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(54) **OPEN OFFSET CANCELING METHOD AND AN IMPEDANCE MEASURING APPARATUS USING THE METHOD**

(75) Inventors: **Koji Tokuno**, Tokyo (JP); **Yoichi Kuboyama**, Tokyo (JP); **Hideki Wakamatsu**, Fukuoka (JP)

(73) Assignee: **Agilent Technologies, Inc.**, Santa Clara, CA (US)

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(58) **Field of Classification Search** 324/610, 324/725

See application file for complete search history.

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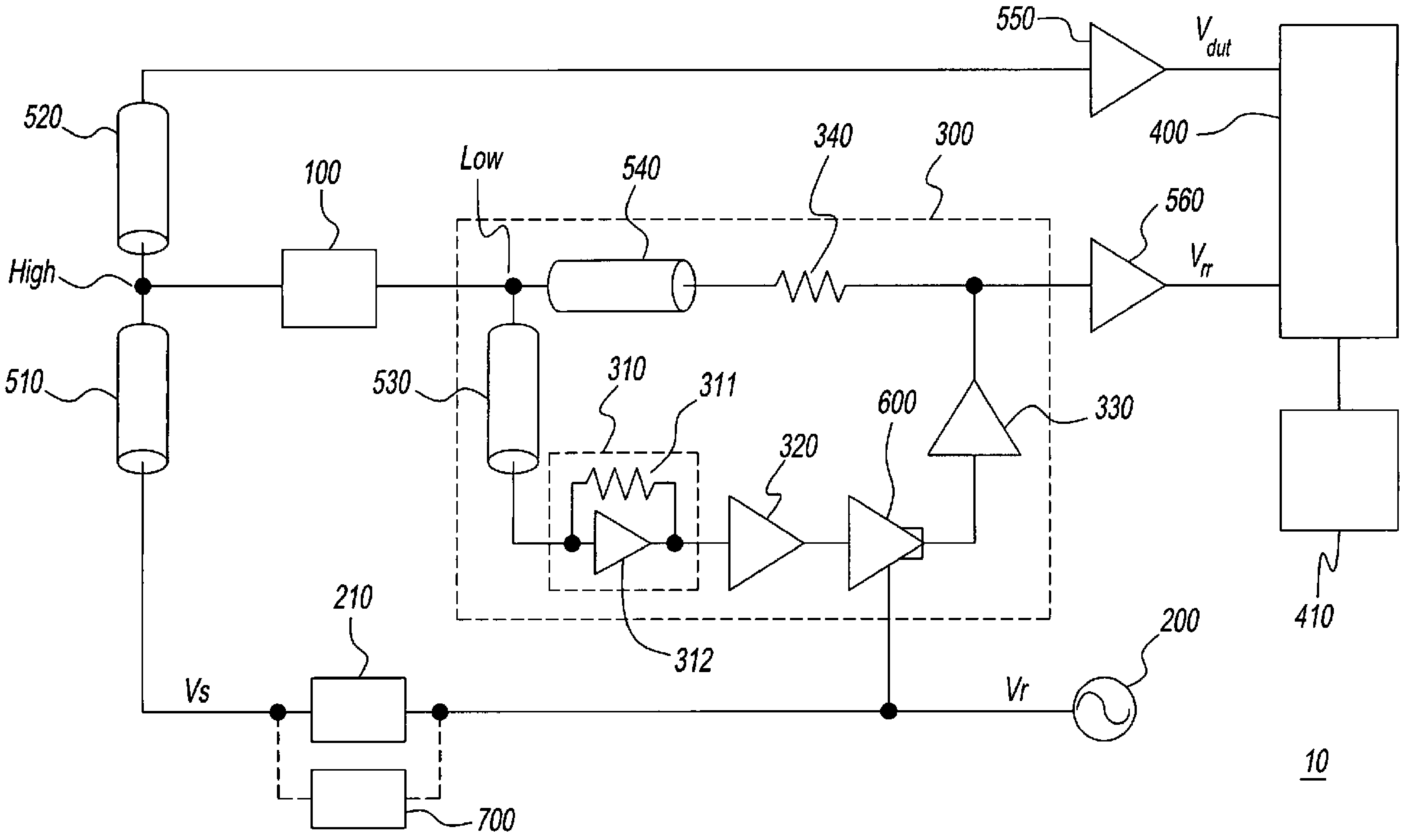
Primary Examiner—Walter Benson
Assistant Examiner—Amy He

(57) **ABSTRACT**

A method for finding the impedance of a device under test using an impedance measuring apparatus having a modem-type auto-balancing bridge, two or more measurement signals, each of which has a different phase with respect to the reference signals supplied to the modem inside said auto-balancing bridge, are applied to a device under test; the impedance of this device under test is measured when each of the measurement signals is applied to the device under test; and the impedance of this device under test is found using the above-mentioned phase and the impedance measurement value of each of these measurements.

6 Claims, 2 Drawing Sheets



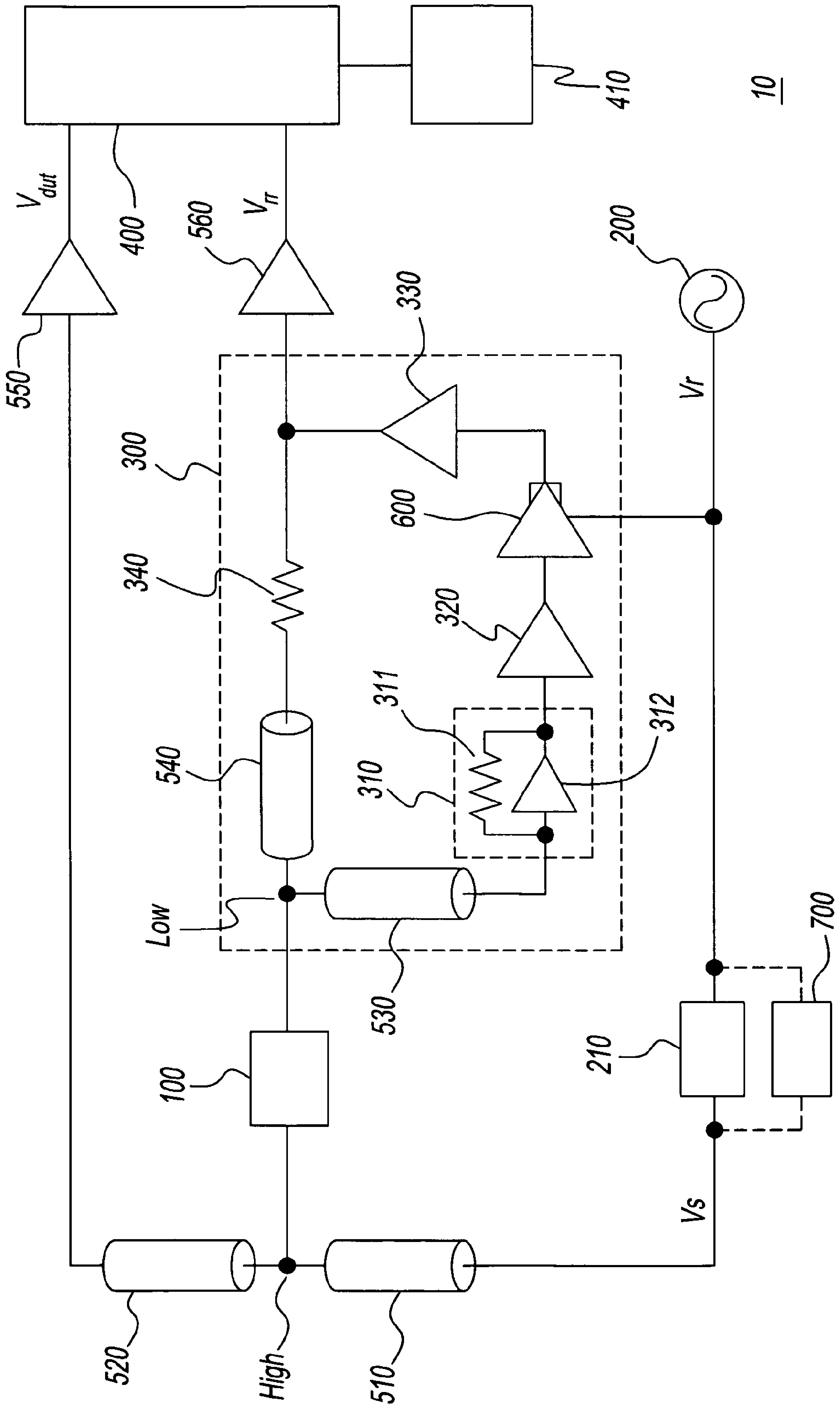

10
410
400
V_{dut}
V_{rr}
560
550
330
300
600
200
Vr
340
320
311
312
310
540
Low
530
700
210
100
Vs
520
High
510

Fig. 1

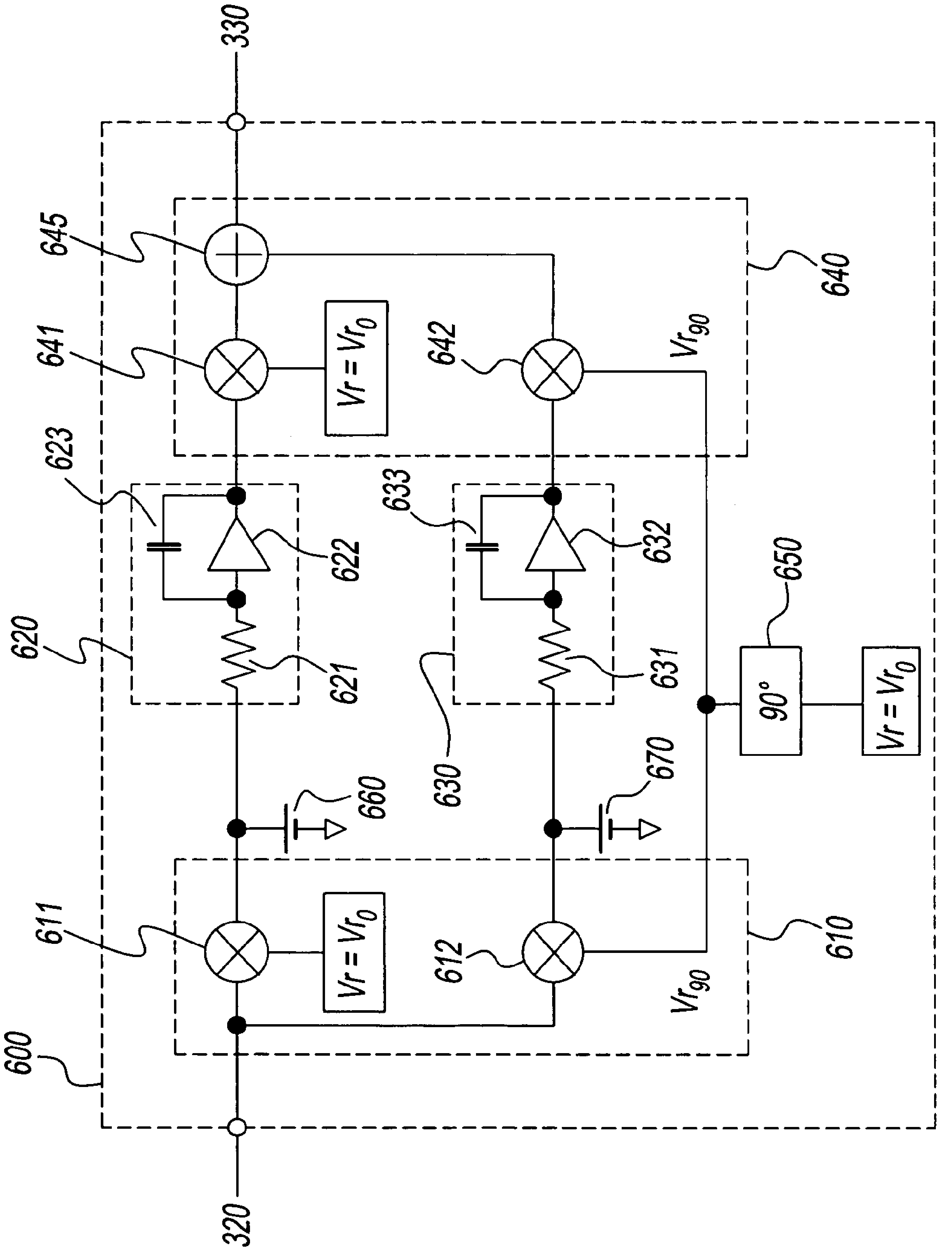

330
645
641
Vr = Vr0
623
622
620
621
633
632
631
630
642
Vr90
640
650
90°
Vr = Vr0
660
670
611
Vr = Vr0
612
Vr90
610
600
320

Fig. 2

OPEN OFFSET CANCELING METHOD AND AN IMPEDANCE MEASURING APPARATUS USING THE METHOD

FIELD OF THE INVENTION

The present invention pertains to impedance measurement technology that uses an auto-balancing bridge, and in particular to impedance measurement technology that uses a modem-type auto-balancing bridge.

DISCUSSION OF THE BACKGROUND ART

The auto-balancing bridge method is one method for measuring the impedance used in the newest impedance measuring apparatuses. Measurement circuits that use the auto-balancing bridge method comprise a signal source for applying measurement signals to a device under test; a current-to-voltage converter for converting the current that flows through a DUT to voltage; and a vector ratio detector for measuring the voltage of measurement signals applied to the DUT and the output voltage of the current-to-voltage converter. The current-to-voltage converter that is used is one which is appropriate for the frequency of the measurement signals. Modem-type current-to-voltage converters are used in conventional measuring apparatuses in order to respond to a broad frequency range. It should be noted that modem means a modulation-demodulation system or modulator-demodulator. Modem-type current-to-voltage converters comprise a null detector, an quadrature detector, an integrator, and a vector modulator. Quadrature detector is referred as phase sensitive detector in below. Vector modulator is referred as vector generator in below. An auto-balancing bridge circuit that uses this modem-type current-to-voltage converter is called a modem-type auto-balancing bridge circuit or simply a modem-type auto-balancing bridge. See JP Unexamined Patent Application (Kokai) 2003-279,607 (pages 2 and 3, FIG. 7).

DC offset occurs in the phase sensitive detector and integrator of modem-type current-to-voltage converters. This DC offset is converted to AC by a vector generator, which is described later and produces an error in the impedance measurement values of the device under test. This difference is called open offset because it can be regarded as constant impedance when a device under test is not connected to the impedance measuring apparatus. An object of the present invention is to eliminate or reduce the effect of open offset on measurement values when measuring the impedance of a device under test.

SUMMARY OF THE INVENTION

In order to solve the above-mentioned problems, the present invention uses two or more measurement signals that are different with respect to the local signal used in the detection part of a modem-type auto-balancing bridge and derives the impedance value of a device under test from which the effect of open offset has been eliminated from the impedance value of the device under test when each of the measurement signals has been applied. The first subject of the invention is a method for measuring the impedance of a device under test using an impedance measuring apparatus having a modem-type auto-balancing bridge, this method characterized in that it comprises a first step for applying to this device under test two or more measurement signals, each of which is a different phase with respect to the same local signal inside this modem-type auto-balancing bridge; a second step for measuring the impedance of this device under test when each of these measurement signals is applied to this device under test; and a third step for finding the impedance of this device under test using the impedance measured values and the above-mentioned phase in each of these measurements.

The second subject of the invention is characterized in that by means of the first subject of the invention, these measurement signals applied to this device under test are two signals, each of which has a phase that is the opposite of the other with respect to this local signal.

The third subject of the invention is characterized in that the first or second subject of the invention further comprises a step for measuring the phase of each of the measurement signals with respect to this local signal.

The fourth subject of the invention is an impedance measuring apparatus having a modem-type auto-balancing bridge, this impedance measuring apparatus characterized in that it comprises a signal source for generating two or more measurement signals, each of which has a different phase with respect to the same local signal inside this modem-type auto-balancing bridge and an arithmetic unit for finding the impedance of this device under test using the above-mentioned phase and the impedance measurement value of this device under test when each of these measurement signals is applied to this device under test.

The fifth subject of the invention is characterized in that by means of the fourth subject of the invention, these measurement signals applied to this device under test are two signals, each of which has a phase that is the opposite of the other with respect to this local signal.

The sixth subject of the invention is characterized in that the fourth or fifth subject of the invention further comprises a device for measuring the phase of these measurement signals with respect to this local signal.

The seventh subject of the invention is characterized in that the fourth or sixth subject of the invention further comprises a vector voltmeter for measuring the impedance of this device under test.

By means of the present invention, it is possible to eliminate or reduce the effect of open offset on measurement values and find an impedance value that is closer to the actual value than in the past when the impedance of a device under test is measured using an impedance measuring apparatus having a modem-type auto-balancing bridge.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing the structure of impedance measuring apparatus **10**.

FIG. **2** is a block diagram showing the internal structure of narrow band amplifier **600**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will now be described while referring to the preferred embodiments shown in the attached drawings.

The first embodiment of the present invention is an impedance measuring apparatus **10** based on the auto-balancing bridge method. Refer to FIG. **1**. FIG. **1** is a block diagram showing the structure of impedance measuring apparatus **10**. Impedance measuring apparatus **10** comprises a signal source **200**, a current-to-voltage converter **300**, a vector voltmeter **400**, and an arithmetic and control unit **410**.

A device under test **100** is an element or circuit having two terminals. Device under test **100** should have at least two terminals, and can be an element or circuit having three or more terminals. In this case, two of the three or more terminals are used in the measurements. Device under test **100** is represented as "DUT" in the drawings. The point connecting device under test **100**, a cable **510**, and a cable **520** is called the high terminal. Moreover, the point connecting device under test **100**, a cable **530**, and a cable **540** is called the low terminal.

Signal source **200** is the device for generating signals Vr, which are reference signals, and is connected to current-to-voltage converter **300**. Moreover, signal source **200** is connected to device under test **100** via a phase shifter **210** and cable **510**. Signal source **200** is further connected to vector voltmeter **400** via phase shifter **210**, cable **510**, cable **520**, and a buffer **550**. Signals Vr are single sine-wave signals.

Phase shifter **210** is the device for adding delay in a predetermined amount to signals Vr and outputting the results. Output signals Vs of phase shifter **210** are applied to current-to-voltage converter **300**. Signals Vs are generally called the measurement signals.

Current-to-voltage converter **300**, which is a modem-type current-to-voltage converter, converts the current flowing through device under test **100** and outputs the voltage signals to a buffer **560**. Current-to-voltage converter **300** comprises a null detector **310**, an alternating-current amplifier **320**, a narrow band amplifier **600**, a buffer **330**, and a range resistor **340**. Cable **530**, null detector **310**, alternating-current amplifier **320**, narrow band amplifier **600**, buffer **330**, range resistor **340**, and cable **540** form a negative feedback loop.

Null detector **310** comprises a resistor **311** and an operational amplifier **312**, and is the device for converting to voltage the current that flows into the input terminal of null detector **310**. Alternating-current amplifier **320** amplifies A-times the output signals of null detector **310** and outputs to narrow band amplifier **600**.

Refer to FIG. **1** and FIG. **2**. FIG. **2** is a block diagram showing the internal structure of narrow band amplifier **600**. Narrow band amplifier **600** comprises a phase sensitive detector **610**, an integrator **620**, an integrator **630**, a vector generator **640**, and a phase shifter **650**, and amplifies the output signals of alternating-current amplifier **320** and outputs to a buffer **330**. Narrow band amplifier **600** separates the output signals of alternating current amplifier **320** into an in-phase component and a quadrature component using phase sensitive detector **610**. The resulting in-phase component and orthogonal component obtained at this time are direct current. Furthermore, the in-phase component is amplified by integrator **620**, while the quadrature component is amplified by integrator **630**, and the amplified in-phase component and quadrature component are modulated by vector generator **640** and vector modulation voltage signals are fed to buffer **330**. As is clear from the drawing, this narrow band amplifier **600** comprises a demodulating part and a modulating part. This is why current-to-voltage converter **300** is called a modem-type IV converter.

Phase sensitive detector **610** comprises a mixer **611** and a mixer **612**. Signals Vr are fed to mixer **611** as local signals for demodulation. Phase shifter **650** is the device for shifting by 90° and outputting the phase of signals Vr that will be input. Here, signals Vr are local signals Vr_0 and the output signals of phase shifter **650** are local signals Vr_{90}. Signals Vr_{90} are fed to mixer **612** as local signals for demodulation. Signals Vr_0 and Vr_{90} have the same frequency and are orthogonal to one another. Consequently, mixers **611** and **612** are capable of orthogonal decomposition of output signals from alternating-current amplifier **320** into an in-phase component and an orthogonal component.

Integrator **620** is an integrator comprising a resistor **621**, an operational amplifier **622**, and a capacitor **623**, and integrates the output signals of mixer **611**. Integrators **620** and **630** have the same structure and mode of operation as a low-pass filter, but the primary objective of integrators **620** and **630** here is to amplify the direct-current component to an infinite quantity.

Vector generator **640** comprises a mixer **641**, a mixer **642**, and an adder **645**. Signals Vr_0 are fed to mixer **641** as local signals for modulation. Similarly, signals Vr_{90} are fed to mixer **642** as local signals for modulation. Signals Vr_0 and signals Vr_{90} have the same frequency and are orthogonal to one another. Mixer **641** modulates signals Vr_0 by the output signals from integrator **620** and outputs the result. Mixer **642** modulates signals Vr_{90} by the output signals from integrator **630** and outputs the result. The voltage signals output from mixer **641** and the voltage signals output from mixer **642** are added by adder **645** and output to buffer **330**.

Voltage source **660** represents the DC offset Vn_0, which is the sum of the DC offset values produced by mixer **611** and by integrator **620**. Moreover, a voltage source **670** represents the DC offset Vn_{90}, which is the sum of the DC offset values produced by mixer **612** and by integrator **630**. There are cases wherein DC offsets Vn_0 and Vn_{90} fluctuate with changes in ambient temperature, or the other condition.

Vector voltmeter **400** measures the output signals V_{dut} of buffer **550** and output signals V_{rr} of buffer **560**. Arithmetic and control unit **410** consists of a CPU, a DSP, or another processor. It calculates the vector ratio of the measured signals V_{dut} and the measured signals V_{rr} and further calculates the impedance measurement value of device under test **100** from the calculated vector ratio and the resistance of range resistor **340**. Moreover, although it is not illustrated, arithmetic and control unit **410** is electrically connected to each structural unit, such as signal source **200** and phase shifter **210**, etc, and controls all of impedance measuring apparatus **10**.

The measurement error produced by DC offsets Vn_0 and Vn_{90} will now be studied. First, $Vr=Vr_0=\sin(\omega t)$. Thus, $Vr_{90}=\cos(\omega t)$ and $Vs=\sin(\omega t+\theta)$. It should be noted that θ represents the initial phase difference, such as the circuit delay.

Moreover, equivalent input signals Vn_{ac} of DC offsets Vn_0 and Vn_{90} are represented as follows: The equivalent input signals Vn_{ac} mean input signals to the narrow-band amplifier **600** to generate DC offsets Vn_0 and Vn_{90} in case of assuming that DC offsets Vn_0 and Vn_{90} are caused by the input signals at the narrow-band amplifier **600**.

$$Vn_{ac}=2\cdot\sqrt{Vn_0^2+Vn_{90}^2}\cdot\sin\left(\omega t+\tan^{-1}\frac{Vn_{90}}{Vn_0}\right) \quad \text{[Mathematical formula 1]}$$

When the resistance of resistor **311** is Rf, the resistance of range resistor **340** is Rr, and the transfer function of narrow band amplifier **600** is H(s), the response Vrrn attributed to signal Vn_{ac} and generated to the output of buffer **560** is represented as follows:

[Mathematical formula 2]

$$Vrrn = Vn_{oc} \cdot \frac{H(s)}{1 + \frac{Rf}{Rr} \cdot A \cdot H(s)}$$

Here, when H(s)>>1 and Rf=Rr, Vrrn≈Vn_{ac}/A. Furthermore, here, $Vn_{ac}/A = Vn_{ofs} \cdot \sin(\omega t + \theta_{ofs})$. When the impedance of device under test **100** is Yd, the impedance measurement value Ymeas of device under test **100** is represented as follows:

[Mathematical formula 3 //

$$\begin{aligned} Ymeas &= Yd - \frac{1}{Vs \cdot Rr \cdot A} \cdot Vn_{ac} \\ &= Yd - \frac{1}{Vs \cdot Rr \cdot A} \cdot 2 \cdot \sqrt{Vn_0^2 + Vn_{90}^2} \cdot \\ &\quad \sin\left(\omega t + \tan^{-1}\frac{Vn_{90}}{Vn_0}\right) \\ &= Yd - \frac{1}{Vs \cdot Rr} \cdot Vn_{ofs} \cdot \sin(\omega t + \theta_{ofs}) \end{aligned}$$

All parts other than the Yd term in the terms at the right of the above-mentioned formula represent the offset error attributed to DC offsets Vn_0 and Vn_{90}. This offset error is also called open offset and is obvious when there is an open connection in place of a device under test. By means of the prior art, a trimmer for offset adjustment is installed at operational amplifier **622**, operational amplifier **632**, or phase sensitive detector **610** is realized by software processing in order to reduce DC offsets Vn_0 and Vn_{90}. In such a case, a rise in the interference rate and an increase in cost and occupied surface area with an increase in the number of components become a problem. Moreover, by means of the prior art, the extent of the effect of the error factors on measurement values is reduced by increasing the amplification factor A. In this case, saturation of the phase sensitive detector due to outside noise becomes a problem. In order to reduce the effect of DC offsets Vn_0 and Vn_{90} on the measurement values, the present invention applies to device under test **100** two or more measurement signals Vs each having different relative phases with respect to the local signal Vr_0(=Vr) used inside narrow band amplifier **600**; separately measures the impedance of device under test **100** when each of the two or more measurement signals Vs are applied to device under test **100**; and finds by mathematical operation the impedance Yd of device under test **100** from the resulting multiple measurement values and relative phase values. The theory of canceling the open offset and finding the actual impedance value of device under test **100** by the present invention will now be described.

Two signals Vs_0 and Vs_1 of different phases with respect to reference signal Vr are applied to device under test **100**. When α_1 is the phase of signal Vs_1 with respect to signal Vs_0, $Vs_0 = \sin(\omega t + \theta)$ and $Vs_1 = \sin(\omega t + \theta + \alpha_1)$. Furthermore, Vs_0, Vs_1, and Vrrn are represented in vector form below. It should be noted that α_1 is the amount of phase shift given by phase shifter **210**. Moreover, α_i is the relative phase or phase difference between measurement signals.

[Mathematical formula 4]

$$Vs_0 = e^{j\theta}$$

$$Vs_1 = e^{j(\theta+\alpha_1)}$$

$$Vrrn = Vn_{ofs} \cdot e^{j\theta,\rho}$$

Moreover, the impedance measurement value $Ymeas_0$ of device under test **100** when $Vs = Vs_0$ and the impedance measurement value $Ymeas_1$ of device under test **100** when $Vs = Vs_1$ are represented as follows:

[Mathematical formula 5]

$$\begin{aligned} Ymeas_0 &= Yd - \frac{1}{Vs_0 \cdot Rr} \cdot Vrrn \\ &= Yd - \frac{1}{e^{j\theta} \cdot Rr} \cdot Vn_{ofs} \cdot e^{j\theta_{ofs}} \end{aligned}$$

$$\begin{aligned} Ymeas_1 &= Yd - \frac{1}{Vs_1 \cdot Rr} \cdot Vrrn \\ &= Yd - \frac{1}{e^{j(\theta+\alpha_1)} \cdot Rr} \cdot Vn_{ofs} \cdot e^{j\theta_{ofs}} \end{aligned}$$

Furthermore, the impedance value Yx is found by substituting $Ymeas_0$ and $Ymeas_1$ represented by the above-mentioned formula in the following formula. Here, the impedance value Yx is equal to the actual impedance value Yd of device under test **100**.

[Mathematical formula 6] (1)

$$Yx = \frac{Ymeas_0 - e^{j\alpha_1} \cdot Ymeas_1}{1 - e^{j\alpha_1}}$$

Let α_1 be π as the simplest embodiment. In this case, the measurement signal Vs_0 whose relative phase with respect to the local signal Vr_0 is 0° is applied to device under test **100** and V_{dut} and V_{rr} at this time are measured by vector voltmeter **400**. Moreover, arithmetic and control unit **410** calculates the impedance measurement value $Ymeas_0$ of device under test **100** from the measured values V_{dut} and V_{rr}. Next, the measurement signal Vs_1 whose relative phase with respect to local signal Vr_0 is 180° is applied to device under test **100** and V_{dut} and V_{rr} at this time are measured by vector voltmeter **400**. Moreover, arithmetic and control unit **410** calculates the impedance measurement value $Ymeas_1$ of device under test **100** from the measured values V_{dut} and V_{rr}. Finally, arithmetic and control unit **410** calculates the impedance value Yd of device under test **100** by $(Ymeas_0 + Ymeas_1)/2$ while referring to measurement values $Ymeas_0$ and $Ymeas_1$, as well as 0° and 180° (π). When α_1 is π, phase shifter **210** can be substituted by an amplifier capable of positive-negative reversal of the multiplication factor. Of course, it is possible to find Yd from formula (1) and any phase value α_1 in cases other than when α_1 is π.

Furthermore, the signals applied to device under test **100** can also be three or more signals, each of which has a different phase with respect to reference signal Vr. For instance, when the signal applied to device under test **100** represents the following n types of signals (Vs_0, Vs_1, . . . , Vs_n), Yd is found by the following formula (2). However, n=2N+1 and N is a natural number. Moreover, θ is the relative phase of signal Vs_0 with respect to reference signal Vr. Furthermore, α_i is the relative phase of signal Vs_n with respect to reference signal Vs_0.

[Mathematical formula 7] (2)

$$\begin{aligned} Vs_0 &= e^{j\theta} \\ Vs_1 &= e^{j(\theta+\alpha_1)} \\ Vs_2 &= e^{j(\theta+\alpha_2)} \\ &\vdots \\ Vs_n &= e^{j(\theta+\alpha_n)} \end{aligned}$$

-continued

[Mathematical formula 8]

$$Yx = \frac{Ymeas_0 + \sum_{i=1}^{n} [(-1)^i \cdot e^{j\alpha_i} \cdot Ymeas_i]}{1 + \sum_{i=1}^{n} [(-1)^i \cdot e^{j\alpha_i}]}$$

The above-mentioned is an example of a case in which the signals applied to device under test **100** are even numbers, but the present invention, of course, is also applicable to cases in which the signals applied to device under test **100** are odd numbers.

However, if the phase of the measurement signal changes, the auto-balancing bridge will become unstable and a waiting time will be produced wherein the measurement cannot start until the auto-balancing bridge has been adjusted. The adjustment time of the auto-balancing bridge that is produced each time the measurement signals are replaced decreases with a reduction in the phase difference between each of the measurement signals. Moreover, when phase difference α_i in formulas (1) and (2) is biased within one period (2π) of measurement signals Vs, for instance, when two or three measurement signals wherein the phase difference between the signals is 20° are applied to the device under test, the measurement difference attributed to the phase control error of phase shifter **210** increases. Therefore, the error is reduced by uniformly distributing the phase differences between measurement signals within one period (2π) of measurement signals Vs and reducing the phase difference by increasing the number of signals, and the settling time is thereby curtailed. Furthermore, **36** measurement signals wherein the phase difference between signals is 10° can be applied to the device under test.

Several modifications relating to the signal source are possible with the present embodiment as long as any one of the local signals used in the modem serves as the reference and two or more measurement signals having a different phase with respect to this reference signal are applied to the device under test. For instance, it is possible to switch signals Vr and signals Vs. That is, it is possible to connect the output of signal source **200** directly to cable **510** and to connect the output of phase shifter **210** to narrow band amplifier **600**. In this case, the output signals of signal source **200** become measurement signals Vs, and the output signals of phase shifter **210** become reference signals Vr. Moreover, it is also possible to use separate signal sources to generate signals fed to device under test **100**, signals fed to mixer **611**, signals fed to mixer **612**, signals fed to mixer **641**, and signals fed to mixer **642** in FIGS. **1** and **2**. However, in this case these signal sources must be synchronized for phase control.

Furthermore, the present embodiment was described using signals Vr_0 inside narrow band amplifier **600** as the phase reference of measurement signals Vs, but it is also possible to use signals Vr_{90} inside narrow band amplifier **600** as the phase reference of measurement signals Vs.

In addition, the present embodiment can also be such that V_{dut} is measured by vector voltmeter **400** in order to know the relative phase α_i between signals Vs_i. There can also be a relative phase measurement device **700** as shown in FIG. **1**. These embodiments are effective in cases in which the phase control precision of phase shifter **210** is poor, and in similar situations.

What is claimed is:

1. A method for measuring the impedance of a device under test using an impedance measuring apparatus having a modem-type auto-balancing bridge, said method comprising:

applying to said device under test two or more measurement signals, each of which is a different phase with respect to the same local signal inside said modem-type auto-balancing bridge;

measuring the impedance of said device under test when each of said measurement signals is applied to this device under test; and

finding the impedance of said device under test using the impedance measured values and said phase in each of said measurements.

2. The method according to claim **1**, wherein said measurement signals applied to said device under test are two signals, each of which has a phase that is the opposite of the other with respect to said local signal.

3. The method according to claim **1**, further comprising measuring the phase of each of the measurement signals with respect to said local signal.

4. An impedance measuring apparatus having a modem-type auto-balancing bridge, said impedance measuring apparatus comprising:

a signal source for generating two or more measurement signals, each of which has a different phase with respect to the same local signal inside said modem-type auto-balancing bridge; and

an arithmetic unit for finding the impedance of said device under test using the above-mentioned phase and the impedance measurement value of said device under test when each of said measurement signals is applied to said device under test.

5. The impedance measuring apparatus according to claim **4**, wherein said measurement signals applied to said device under test are two signals, each of which has phase that is the opposite of the other with respect to said local signal.

6. The impedance measuring apparatus according to claim **4**, further comprising a device for measuring the phase of said measurement signals with respect to said local signal.

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